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Magnetic Resonance Imaging / Formation image de résonance magnétique

MRA: Current Applications in Body Vascular Imaging

Viesha A. Ciura, MD[a], Mark J. Lee, MD[a,*], Drew C. Schemmer, MD[a,b]

[a]*Department of Diagnostic Imaging, Foothills Medical Centre, Calgary, Alberta, Canada*
[b]*Department of Diagnostic Imaging, Royal Victoria Hospital, Barrie, Ontario, Canada*

Computed tomography (CT) angiography (CTA) and magnetic resonance (MR) angiography (MRA) are 2 modalities that have revolutionized the field of diagnostic vascular imaging. Conventional catheter angiography, which was once the gold standard, is now being replaced by CTA and MRA because of their lower cost and noninvasiveness. Advancements in cross-sectional imaging include higher spatial and temporal resolution, as well as the ability to construct three-dimensional (3D) images from volumetric data and to view vessels from multiple angles [1].

CTA is traditionally more widely used than MRA, mainly because of availability and greater CT expertise. Other advantages of CTA over MRA include faster acquisition times, higher spatial resolution, and utility in patients with contraindications to MR imaging, including certain aneurysm clips, cochlear implants, pacemakers, and claustrophobia [1,2]. Current uses of CTA are many, including perioperative imaging and planning of endovascular aneurysm repairs (EVAR) and imaging of the abdominal aorta and visceral vessels [3]. Disadvantages of CTA include the use of ionizing radiation and iodinated nephrotoxic contrast material, 2 factors that make MRA a more desirable modality.

Using MR to delineate vascular anatomy has changed dramatically since first described in 1985 by Wedeen et al [4]. Technology continuously evolves and provides more advanced equipment and complex software, which is faster and provides more detailed information. MR sequences such as phase-contrast (PC) MRA (PC-MRA) and time-of-flight (TOF) MRA (TOF-MRA) provide reasonable depictions of the vascular anatomy without contrast. Research into non-nephrotoxic, gadolinium-based contrast agents has paved the way for contrast-enhanced MRA (CE-MRA), which today is widely used in clinical practice [5].

MRA is gaining popularity as applications increase image quality and decrease acquisition time. Dynamic MRA acquisitions (time-resolved imaging of contrast kinetics [TRICKS; GE, Buckinghamshire, United Kingdom] and syngo TWIST [Siemens, Munich, Germany]) are relatively new and beneficial techniques that shorten acquisition times by obviating contrast-injection timing tests [6,7], acquire temporal data that can be reviewed as a cine loop, and replicate conventional digital subtraction angiography (DSA) sequences. Desired images can then be selected retrospectively to create 3D images.

Advantages of MRA over CTA include increased signal-to-noise ratio, easier 3D postprocessing, and utility in patients with renal dysfunction, such as diabetics [2,3]. In patients who require recurrent follow-up imaging, MRA is superior, given its lack of ionizing radiation. MRA is often used to image the visceral aortic branches and in many centers is the gold standard for visualizing the renal arteries. MRA has also been shown to be valuable in the preprocedural and follow-up of patients undergoing aortic EVAR. In the planning stages, CE-MRA has been shown not only to be as accurate as CTA but able to provide functional, hemodynamic information that CTA cannot. As well, common delayed complications, for example, endoleak, are more conspicuous with contrast-enhanced MRA [8]. Other applications of MRA include cerebrovascular imaging and visualization of the infrainguinal arterial system [2].

In this article, the investigators provide a pictorial journey through some of the many applications of body MRA. Hyperlinks to web videos are provided to see some of these applications in real time. Also, future applications of MRA and the impact of functional information derived from MR will be discussed.

Vascular Thoracic Outlet Syndrome

The thoracic outlet comprises 3 spaces: the interscalene triangle, the costoclavicular space, and the retropectoralis minor space (subcoracoid tunnel) [9]. Vascular or nervous compression within one of these spaces leads to thoracic outlet syndrome (TOS). Clinical diagnosis is made through eliciting symptoms through various dynamic movements of

* Address for correspondence: Mark J. Lee, MD, Department of Diagnostic Imaging Foothills Medical Centre, 1403 29 Street NW, Calgary, Alberta T2N 2T9, Canada.

E-mail address: mark.lee@calgaryhealthregion.ca (M. J. Lee).

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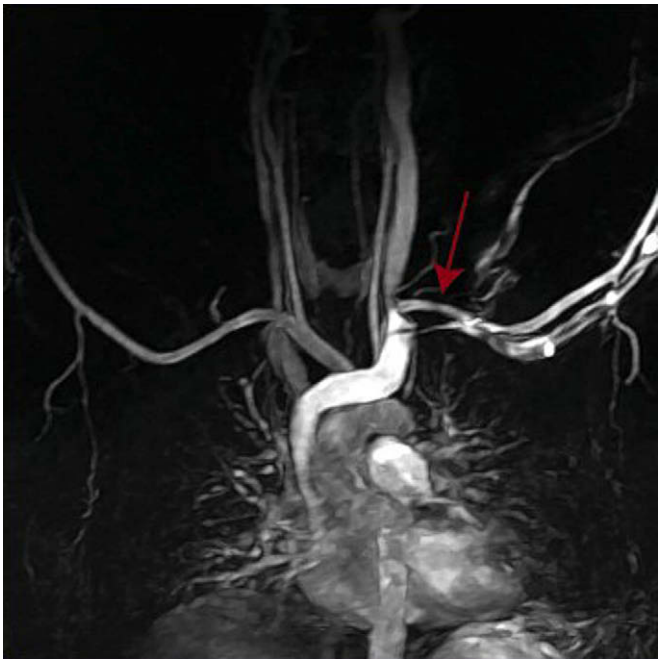

Figure 1. Time-resolved imaging of contrast kinetics (TRICKS) magnetic resonance (MR) angiography (MRA) of the thoracic outlet in a 55-year-old man in the challenged positioning (arm abducted), showing critical mechanical stenosis of the left subclavian vein (red arrow). There are multiple collaterals, showing holdup of contrast proximally and peripherally. Technique: 7.5 mL Gadovist (Berlex; Bayer Healthcare Pharmaceuticals, Montville, NJ), 20 mL NS push, matrix 256 × 192, 2-mm thick, TR: 1 sec. NS = normal saline.

the affected arm [10]. Given that normal subjects can exhibit similar symptoms during abduction maneuvers, imaging studies should confirm the diagnosis [11]. Several studies showed the usefulness of MR in delineating neurovascular structures as they pass through the aforementioned spaces [11,12]. MR imaging of suspected vascular TOS is conducted with the arm in 2 positions: adduction, followed by hyperabduction. If imaging demonstrates compression of either the subclavian artery or vein and is correlated with clinical symptoms, then a diagnosis of vascular TOS can be made [11]. See Figures 1 and 2 for examples of this.

Conventional angiography has traditionally been the gold standard for imaging vascular TOS because of its high resolution, however, it is invasive, requires the use of iodinated contrast, and does not always allow the cause of the compression to be determined [13]. MRA is perfectly suited to the imaging of vascular TOS, with its high spatial resolution, noninvasiveness, and short acquisition times [14]. Use of MRA to evaluate TOS requires 2 positions, neutral and challenged, and 2 separate contrast injections, but can be dynamically interrogated by using TRICKS or TWIST techniques. TRICKS in real time is demonstrated in Video 1. Dynamic MRA avoids the potential for residual intravascular contrast contaminations and reduced signal-to-noise ratios. Two separate static MRA studies examined this potential pitfall and concluded that image quality was rarely impaired by the increased background contrast, because they were able to achieve detailed images of both the arteries and veins in both arm positions [11,15]. MRA, with its superior soft-tissue imaging capabilities, has the distinct advantage of demonstrating the underlying cause of TOS, whether it is congenital bony or fibromuscular anomalies, trauma, or posture. Ultimately, TOS is a surgical and/or clinical diagnosis, and a multidisciplinary approach is paramount.

Peripheral Arterial Disease

Peripheral MRA is a safe and noninvasive procedure that can be used to evaluate renal, aortoiliac, and distal runoff

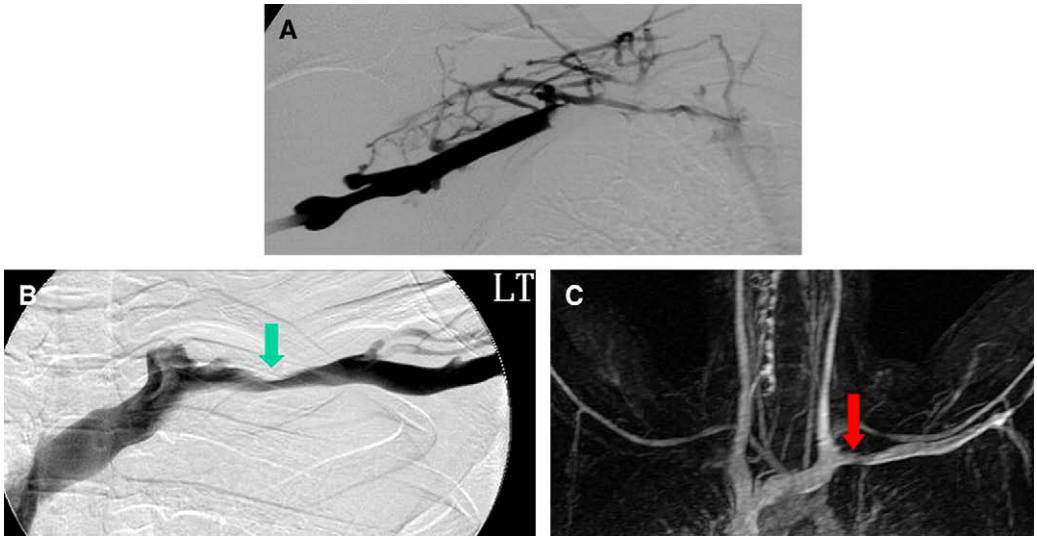

Figure 2. Bilateral subclavian vein stenosis. (A) Conventional angiogram, showing residual thrombosis in the right subclavian vein. Note the meniscus, which represents an intraluminal thrombus. (B) Second conventional angiogram in the same patient, demonstrating moderate stenosis of the left subclavian vein (green arrow). (C) TRICKS MRA of both arms in the challenged positioning (both arms abducted), showing congruency with the digital subtraction angiography (DSA) venogram: right subclavian vein residual thrombosis and moderate stenosis of the left subclavian vein (red arrow). Technique: 7.5 mL Gadovist, 15 mL NS bolus push, matrix 256 × 192, 2-mm thick, TR: 2 sec.

arteries. Images are acquired from the suprarenal aorta down to the foot as the contrast agent flows through the vessels. MRA is highly specific and sensitive in detecting stenoses and aneurysms in the aortoiliac and distal femoral vessels.

Peripheral arterial disease (PAD) is defined as the manifestation of atherosclerosis in the lower limb distal to the aortic bifurcation. Initial presentation of PAD is usually intermittent claudication, which can progress to critical limb ischemia. Imaging of PAD is indicated when the symptoms become apparent and intervention by revascularization is considered. The first randomized controlled trial that compared CTA and MRA in evaluating PAD was performed recently, and there was no significant difference in clinical utility and patient outcomes between the 2 modalities [16], although CTA did have the advantages of lower total diagnostic costs and greater therapeutic confidence. However, with the annual rapid increase in renal impaired patients, MRA safety and its applications are becoming far more robust. As MRA experience increases diagnostic confidence will follow.

It has been suggested that diagnostic utility of MRA and CTA in detecting PAD is variable, depending on the anatomic level of the disease and the degree of venous contamination [17,18]. The infrapopliteal region is poorly visualized by CTA because of the small-diameter arteries [19], and highly calcified vessels are the nemesis of CTA luminal evaluation. MRA contrast media fills the vessel lumen, and the inherent MR and subtraction techniques circumvent calcification artifacts, altogether making its utility in patients with diabetes and with calcified vessels superior to CTA and DSA. Also, dynamic MRA techniques can replicate real-time inflow of contrast media, as in DSA, and show superior vessel analysis of stenoses, compared with standard, nondirectional, MRA and CTA techniques. Examples of the dynamic nature of MRA and its utility in evaluating PAD are seen in Figure 3 and Videos 2 and 3. Also, the sequelae of atherosclerosis is demonstrated in Video 4, but the case involves the vessels of the wrist and hand.

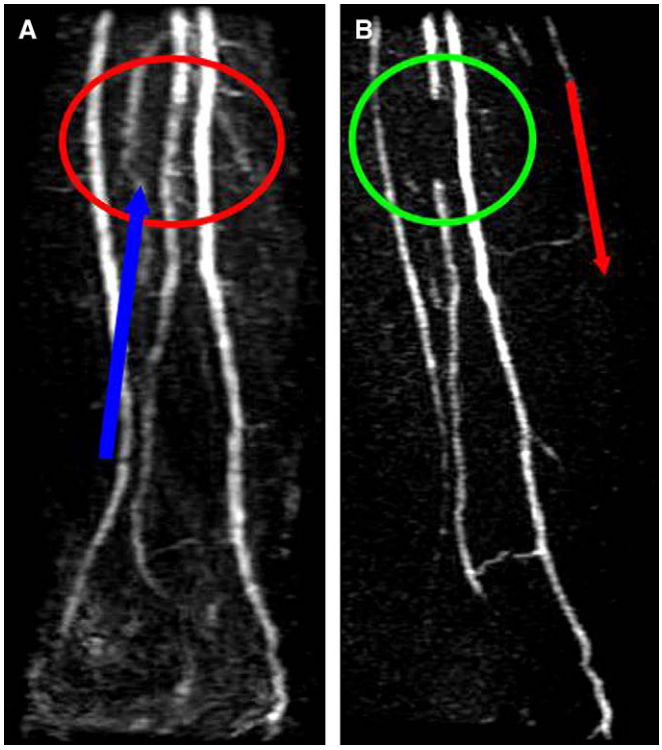

Figure 3. Clinical history of right leg claudication. This case demonstrates the directional differences between conventional contrast-enhanced (CE) MRA and temporal MRA studies (TRICKS). (A) CE-MRA, in which injected contrast fills as many vessels as possible over time, and the resultant display erroneously represents a falsely patent artery by retrograde arterial flow (blue arrow). (B) Temporal MRA (TRICKS) accurately identifying an occlusion of the same peroneal artery because of multiple progressive MRA images and prograde filling (red arrow) of the anterior tibial and posterior tibial arteries with retrograde filling of the peroneal artery. There is no sacrifice of image quality or signal-to-noise ratio because of temporal speed. Technique: 7.5 mL Gadovist, 20 mL NS bolus push, matrix 256 × 160, 2-mm thick, Sp 1 mm, TR: 2 sec. Sp = spacing.

Renal Artery Stenosis

In 1934, Goldblatt et al outlined the pathophysiology of renal artery stenosis (RAS) and its association with systemic hypertension [20]. Subsequent research demonstrated the complexity of this relationship, because RAS may occur alone or in association with systemic hypertension and/or renal insufficiency. Individuals with essential or primary hypertension can also have RAS, which, even if corrected, the individuals' blood pressure remains elevated [21].

The majority of cases of RAS are caused by either atherosclerosis or fibromuscular dysplasia. Atherosclerosis accounts for up to 90% of cases of RAS, and its prevalence increases with age and other comorbidities, such as diabetes and coronary artery disease [5,21]. It usually involves the ostium and proximal third of the main renal artery and perirenal aorta [22,23]. Fibromuscular dysplasia covers a group of conditions that involve fibrous or muscular proliferation with involvement of the vascular media (90% of the time). It rarely progresses to complete occlusion of the artery when compared with atherosclerotic RAS.

RAS severe enough to decrease renal perfusion initiates the renin-angiotensin system and elevates systemic blood pressure. The ultimate goal is to noninvasively evaluate patients who are hypertensive and with as little effect on the kidneys as possible. Although DSA is the gold standard for anatomic delineation, complicating factors, such as contrast nephrotoxicity and possible anaphylaxis, makes it less attractive. A meta-analysis that compared noninvasive or minimally invasive diagnostic techniques currently used found that CTA and MRA were superior to ultrasound, captopril renal scintigraphy, and the captopril test [24].

CE-MRA has become the imaging modality of choice, because not only is it noninvasive but it uses non-nephrotoxic contrast agents to delineate renovascular pathology [25–28]. Studies since 1994 have shown high sensitivity and specificity for both nonenhanced and contrast-enhanced MRA in the detection of RAS [22,29]. MRA has also shown its value in delineating the vascular anatomy before revascularization, assessing renal bypass grafts, and evaluating vascular

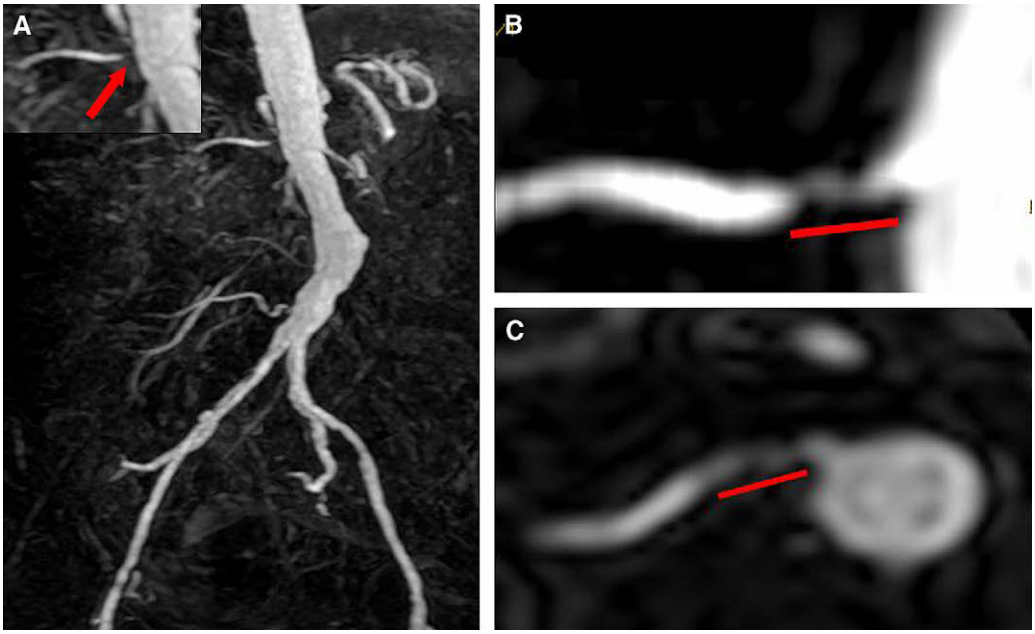

Figure 4. (A–C) Renal artery stenosis. CE-MRA examination of the right renal artery, showing mildly irregular but patent renal arterial lumen after 6-mm balloon angioplasty. In these situations, noninvasive MRA surveillance is recommended every 6 months for the first year, with another examination if the patient's blood pressure, creatinine, and/or glomerular filtration rate levels become abnormal.

complications postrenal transplantation. More importantly, MRA also provides functional information concerning renal hemodynamics, such as renal perfusion, glomerular filtration rates (GFR), tubular concentration and transit, diffusion, and oxygenation [27,30,31]. The application of MRA in the evaluation of RAS is shown in Figures 4–6.

When evaluating stenotic lesions, widely accepted criterion is that a stenosis comprising an perpendicular area of 75% (theoretically corresponding to 50% diameter) is considered hemodynamically significant [32]. Schoenberg et al [26] demonstrated that evaluating the perpendicular area was far more reliable than measuring the stenosis diameter. However, some investigators would argue that revascularization of a severely stenotic lesion may be unnecessary if renal parenchymal impairment has already occurred. Renal compromise would mean slow blood flow and the absence of a pressure gradient beyond the stenotic lesion [31].

Before CE-MRA, noncontrast techniques, such as TOF and PC, were used to delineate vascular anatomy, however, they were limited by diminished vascular flow in patients with severe stenosis or parenchymal disease and respiratory motion artifact. Many centers today combine CE-MRA with noncontrast two-dimensional (2D) and 3D cine PC sequences to add functional information to the anatomic information. Combining multiple sequences within a single examination provides a plethora of diagnostic information: anatomy of the kidney and adrenals (morphology, presence of cysts or neoplasms), arterial and venous anatomy, gadolinium transit and clearance rate, pressure gradients, and measurement of blood flow to each kidney [27].

Some patients receive renal artery endoluminal MR-compatible stents to correct the RAS and warrant the safest means of follow-up. These new MR-compatible stents are composed of cobalt chromium and allow evaluation of renal artery patency after intervention. Technically, the shortest TE should be used to decrease dephasing, with a bandwidth around 62.5 KHz. A high flip-angle (commonly 60°) is needed to avoid radiofrequency (RF) shielding. Examples of RAS with MR-compatible stents are shown in Figures 4–6.

Role of MRA in Aortic Disease and Endovascular Aneurysmal Repair

MRA is capable of evaluating the aorta in a noninvasive 3D manner with innumerable postprocessing angles and views. Aortic diseases seen with MRA can be evaluated with respect to the lumen and to mural and extramural structures. Aortic lumens can retain plaque, tumour, or thrombus, whereas regional or adjacent structures may relate to the underlying vascular disease, all within diagnostic capabilities of MR and MRA. The aortic wall can also be evaluated in disease processes, such as inflammatory aortitis from idiopathic, infectious, or autoimmune etiologies. Examples of inflammatory abdominal aortic aneurysm (AAA) are seen in Figure 7 and Video 5. MRA with fat saturation, as well as pre- and postgadolinium sequences can clearly identify the inflamed and enhancing aortic wall and fibrous thickening, as well as aortic dilatation and/or stenoses.

Repair of AAAs has changed dramatically over the past decade. Since the early clinical trials described by Parodi et al [33], EVAR has evolved as a widely used, less-invasive alternative for treating patients with AAAs [34]. EVAR is associated with reduced blood loss, fewer postoperative complications, decreased need for intensive care unit stays,

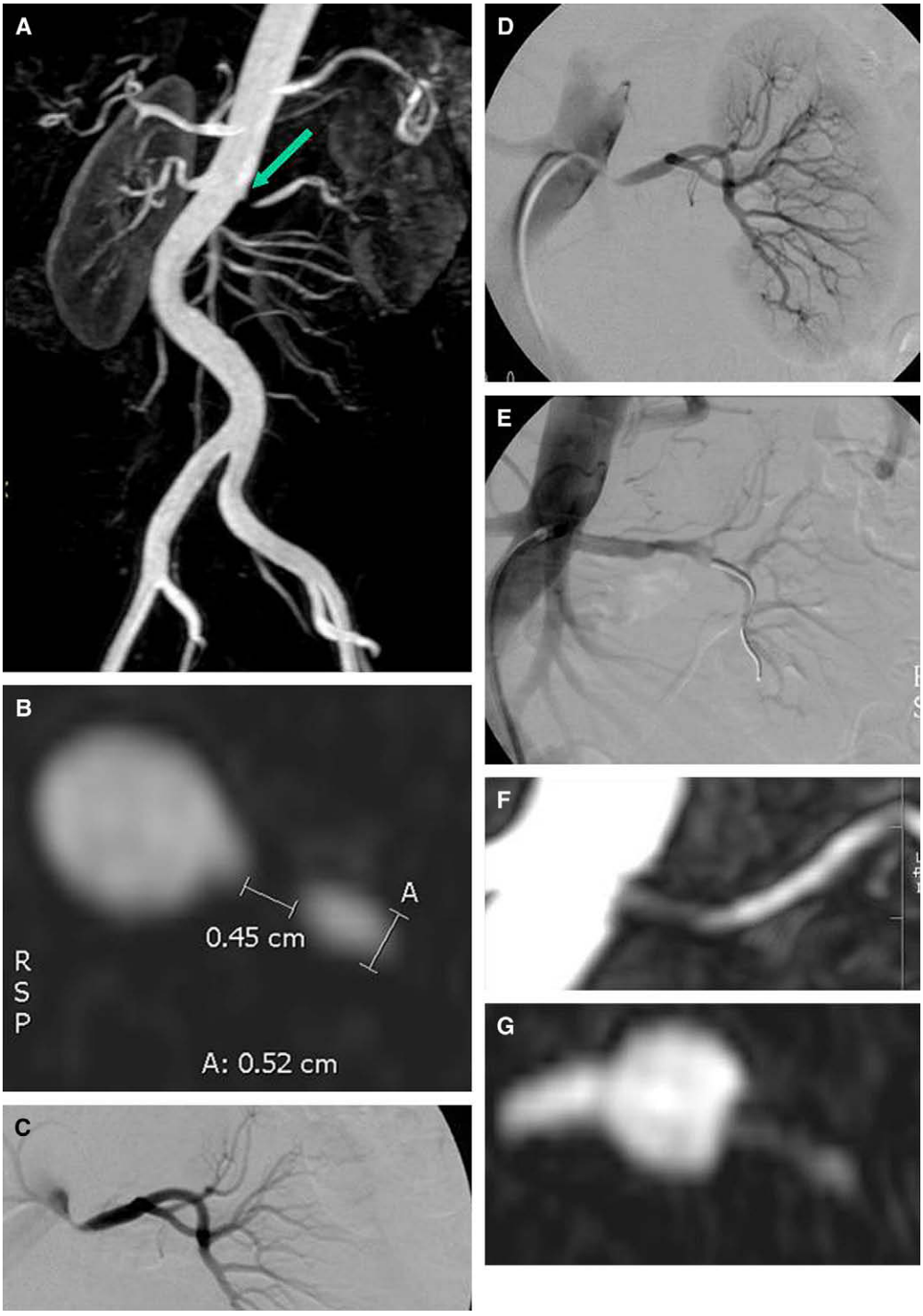

Figure 5. A 58-year-old woman with a clinical history of hypertension and elevated creatinine. (A) Present MRA, demonstrating severe left renal artery stenosis (green arrow) with high flow signal void in renal ostium. (B) Present axial multiplanar reconstructed (MPR) allows for the delineation of the stenosis length and underlying native renal calibre. This facilitates preprocedural selection of the most accurate and safe renal artery stent. Technique: MRA 7.5 mL Gadovist, 15 mL NS bolus push, matrix 256 × 192, 0.71 NEX, 2.4-mm thick, Sp 1.2 mm. (C, D) Two DSA images show severe left renal artery stenosis with normal nephrogram. (E) DSA image, showing a 7 × 12-mm MR-compatible stent after balloon angioplasty and reveals excellent improvement in vessel calibre. (F, G) Post-MRA visualization of left renal artery with MR compatible cobalt chromium Racer (Medtronic, Minneapolis, MN) stent in situ. Sagittal (F) and MPR (G) images further delineate the calibre of the stent. NEX = number of excitations.

and an overall more rapid recovery when compared with open repair [35]. These advances, however, have precipitated ever-increasing demands on diagnostic imaging to provide high-resolution, accurate analyses of the abdominal vasculature. In the EVAR planning stages, accurate morphologic measurements of the aorta and adjacent vasculature must be

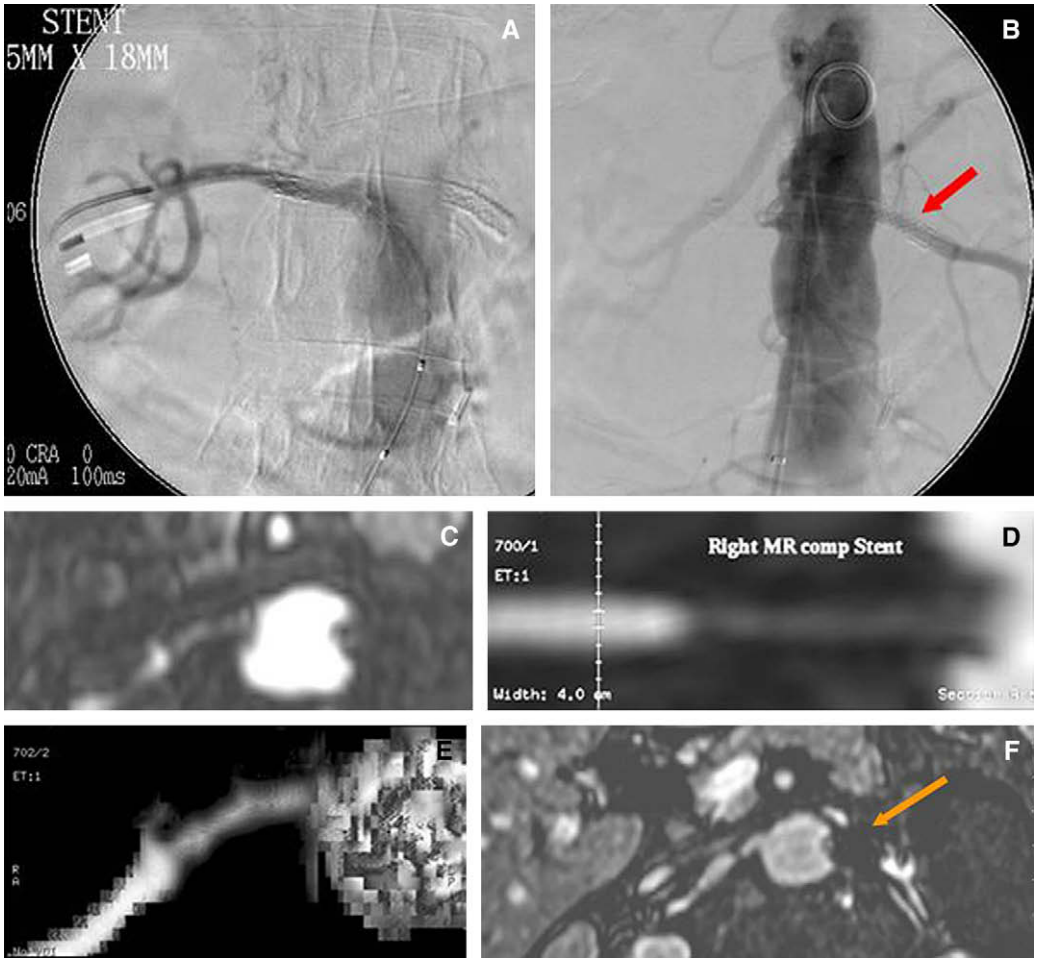

Figure 6. A 73-year-old woman with bilateral renal artery stenoses, who had previously had a left stainless steel renal stent inserted. (A, B) DSA-guided insertion of MR-compatible cobalt chromium Racer stent in the right renal artery. The stainless steel stent in the left renal artery is indicated by the red arrow. (C–F) Post–MR-compatible Racer stent insertion. Multiple direct coronal and reconstructed axial MRA projections of the renal arteries, as well as MPR and vessel analysis reformations of the right renal artery after stenting. Note the significant metallic susceptibility artifact in the region of the left renal artery with its stainless steel stent (E). The orange arrow (F) points to the stainless steel stent in the left renal artery, which makes interpretation of the arterial lumen nondiagnostic.

obtained [36]. Inaccurate measurements can potentially lead to complications, such as endoleak and stent migration [37]. Morphologic measurements include length and diameter of the proximal aortic neck, aortic contour, delineation of thrombus and/or calcification, angle between aortic neck and suprarenal aorta, calculated stent-graft length, and characterization of the iliac and renal arteries [38]. An example of an MRA image obtained for preoperative EVAR workup is given in Figure 8, and the utility of MRA in evaluating EVAR after surgery is shown in Video 6.

Various imaging modalities have been assayed, however, CTA and MRA have emerged as the most reliable modalities for pre- and postprocedural assessment [39,40]. MRA of patients with EVAR requires the implantation of MR-compatible nitinol products. MRA has not only been shown to be a reliable alternative [41] but can supercede the capabilities of CTA when evaluating for the presence of endoleak [42,43]. Some investigators found that serious complications, for example, endoleaks, are better delineated by MRA [40,43]. See Figure 9 for an example of the capability of MRA in detecting endoleak.

MRA images are obtained as a true 3D data set, which supercedes the 2D images of DSA and Doppler ultrasound [26]. With advancement of technology and faster scanning times, achieving optimal blood-to-background contrast has become more difficult. Gadobutrol (gadolinium-DO3A-butriol, Gadovist; Bayer Schering Pharma, Leverkusen, Germany), one of the newer MRA contrast agents, can be used at 1.0 mmol/mL (most solutions for CE-MRA are 0.5 mmol/mL), without adversely affecting electrocardiographic measurements and renal function [25]. The higher concentration thus provides higher intravascular signal and enhances blood-to-background contrast. Other advantages of MRA reports by some investigators have been significantly decreased postprocessing times with MRA, up to 60 times shorter than CTA [38,39,44].

A consistent shortcoming of MRA has been its higher cost and decreased availability when compared with CTA. As well, scanning time is longer, which can be difficult for some patients, and, therefore, for emergent cases, CTA is more appropriate [5]. Delineating small accessory renal vessels and grading RAS has been shown to be more sensitive and

Figure 7. Inflammatory abdominal aortic aneurysm (AAA) treated with a Medtronic nitinol stent 1 month earlier. (A) Preoperative Gadovist-enhanced MRA of the abdominal aorta clearly showing enhancing mural thickening of the infrarenal aorta (red arrows). Intraluminal aortic thrombus (black) and luminal contrast (grey) are also well delineated. (B) MRA MIP, showing visceral anatomy and luminal aortic contours. (C) Postoperative coronal MRA of MR-compatible (nitinol-Medtronic) EVAR, with patent limb grafts and persistent aortic mural thickening and enhancement. No evidence of endoleak. MIP = maximum intensity projection.

specific with CTA [39]. Delineating the full extent of mural calcifications has also been shown to be more accurate with CTA, which is important for planning of EVAR cases. Overall, MRA has consistently demonstrated its ability to provide accurate information necessary for EVAR, parallel with that provided by CTA and/or DSA [38,45].

Functional information gleaned from MRA may ultimately tip the scale when deciding between MRA and CTA. Anatomical information demonstrated on MRA is superior to conventional DSA and continually competes with CTA as a viable alternative. However, anatomic information may not always coincide with physiologic consequences, as is the case with RAS. Hemodynamic information, such as flow velocity and organ perfusion, elucidates the lesions that are actually contributing to vascular compromise and organ demise. In addition, this added information can be acquired while anatomic outlines are being made, which means that the patient does not have to return for another examination. For this reason, MRA has proven to be a valuable tool, able to manage a patient from the preprocedural evaluation and morphologic assessment all the way through the postprocedural surveillance stages.

Dynamic MRA Bolus Chase Third Station Evaluation: TRICKS and TWIST

These are relatively new and beneficial techniques that shorten acquisition times by obviating contrast injection timing tests [6,7], acquire temporal data that can be reviewed as a cine loop, and replicate conventional DSA sequences.

TRICKS and TWIST are innovative techniques that capitalize on the existing technology of standard bolus chase CE-MRA. Before CE-MRA, 2D TOF-MRA emerged as an attractive alternative to DSA, however, drawbacks, such as lengthy examination times, movement artifact, and significant signal-to-noise losses, hindered its widespread acceptance [5]. With the inception of CE-MRA, 3D images are acquired faster and with enhanced vessel-to-background contrast, without being as susceptible to artifacts that complicate TOF-MRA.

To properly image the vasculature as contrast passes through, careful planning must be done to time the procedure for maximum vessel signal. Images that are 2D are used with a test bolus to measure the delay between injection and maximum vessel filling, at which time data sampling should take place. Software packages such as BolusTrak (Philips, Best, The Netherlands) and CareBolus (Siemens) provided a streamlined method of automating this process that removed the need for a test bolus scan. ‘‘Real-time’’ bolus monitoring allowed the entire contrast volume to be administered while the true 3D CE-MRA examination was taking place.

One of the major issues complicating CE-MRA images has been background venous enhancement. A recent technique described by Korosec et al [6] involves repetitively sampling the center of k-space while leaving peripheral data to be collected towards the end of the examination. Both data sets are then temporally interpolated to provide images with enhanced spatial resolution, increased vessel-to-background contrast, and reduced contaminating venous enhancement. Also, TRICKS obviates the need for timing software and other strategies to reduce venous enhancement, such as image masking [5].

Potential Complications and Controversies of MRA Contrast Agents

Despite millions of patients receiving MRA contrast media, many of whom are specifically selected because of

Figure 8. MRA for preoperative endovascular aneurysm repair (EVAR) workup. Accurate spatial resolution allows endovascular radiologists to document renal anatomy, infrarenal aortic neck lengths, and pelvic arterial dimensions.

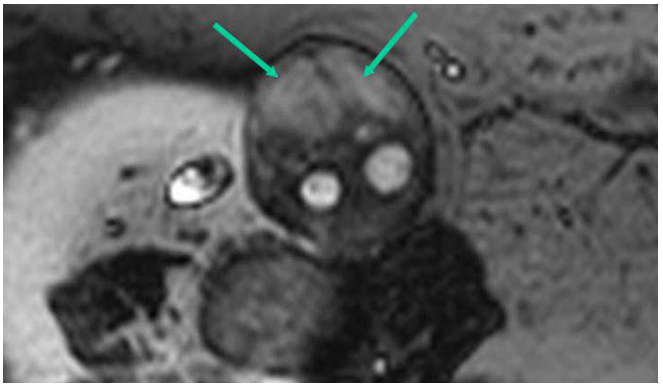

Figure 9. Axial MRA image of postoperative EVAR of infrarenal AAA. Contrast is seen in each widely patent limb graft. However, there is contrast seen in the aneurysm sac external to the graft stent (green arrows) consistent with a significant type II endoleak.

their underlying renal failure, some may be at risk for a progressive, irreversible, and potentially fatal disease called nephrogenic systemic fibrosis (NSF). Just over 100 worldwide, non-Canadian, cases of NSF have been reported after the administration of gadolinium. Some patients with NSF were never exposed to gadolinium, whereas others were thought to be a higher risk because of their lower GFRs.

Patients with NSF can develop thickening of the skin and connective tissues that causes significant morbidity that to date is untreatable. There are ongoing efforts to validate and isolate the actual causes of NSF and their potential causal relationship with gadolinium-based contrast agents (GBCA). A few studies found that the majority of cases originated from Omniscan (gadodiamide; GE Healthcare, Olso, Norway) [46–48]. On May 23, 2007, the Food and Drug Administration (FDA) called attention to observed serious adverse reactions of patients with NSF and with renal failure, just before or after liver transplantation, or those with chronic liver disease.

There are theories that NSF is related to GBCA chelation architecture, severity of renal failure, and dose dependence [46–50]. The possibility of transmetallation and liberation of free gadolinium from a chelating agent may be 1000 times higher in an agent like gadodiamide. Macrocyclic GBCAs may be more resistant to cleavage and/or release of free toxic gadolinium [48–50]. Recommendations to reduce the risk of NSF include obtaining both creatinine and GFR values, specifically in patients with severe renal insufficiency, stage 4 or higher, or with a GFR <30 mL/min per 1.73 m^2; weigh the risk of CE-MR imaging in patients with impaired renal function vs the risk without GBCA, not test at all, or use CE CT with ionizing radiation. In all cases in which significant chronic renal failure (CRF) cases are unavoidable, the GBCAs should be minimized [48–50]. The FDA suggests that NSF can occur after use of any of the GBCAs in certain patients and that ''black box'' warnings be added to product labeling of all GBCAs, further suggesting that ''GBCAs play a role in NSF development'' but have not been ''definitively determined'' to do so (FDA web site). For more information see www.fda.gov/cder/drug/infopage/gcca/default.htm.

New and Future Experimental MRA Contrast Agents

Intravascular and plaque-specific contrast agents are 2 examples of new and future compounds being used in MR vascular imaging. MRA contrast media currently is based on extracellular mechanics that rapidly extravasates, limiting study acquisition times, spatial resolution, and contrast-to-noise ratios. The creation of intravascular agents that are

retained in the vascular system would prolong imaging time and allow for the reduction of voxel sets from 1−2.5 mm^3 down to less than 0.5 mm^3, approaching the resolution of DSA imaging.

Intravascular contrast agents include media such as gadofosveset trisodium (Vasovist; Bayer Healthcare Pharmaceuticals, Montville, NJ) (protein binding) for visceral and peripheral vessels, and gadomer (macromolecule) for cardiac and coronary MR evaluations. Gadomer-17 (Bayer) is a synthetic agent with a large molecular weight that is linked to gadolinium. The renal excretion is slow because of its size, and, thus, it provides longer vascular enhancement. An arterial plaque-specific research contrast agent is being investigated (Gadofluorine; Bayer) in hopes of detecting stability of arterial plaques.

Vasovist reversibly binds to serum albumin, which results in longer and significantly greater (16 times) vascular enhancement. In addition to providing excellent first-pass MRA analysis, it also provides prolonged serum retention and delayed extravasation. Advantages of Vasovist include reduced contrast volumes (<10 mL, 0.03 mmol/kg), superior spatial resolution (voxel size <0.5 mm^3, close to DSA), and use with longer acquisition times (up to 1 hour), with repeated imaging if necessary. Current blood pool MRA uses include body MRV (inferior vena cava/pelvic) and runoff MRA and MRV cases. Future gadofosveset trisodium applications may include thoracic MR venography and vessel wall and plaque analysis. This contrast agent is excreted primarily by the kidneys and has yet to be implicated in NSF. Its prolonged retention and linear anatomical configuration may be balanced by its albumin chelation and low dose demands for MRA examinations.

Conclusion

MRA has come a long way since its initial inception. There are many new and innovative applications that have revolutionized the way we look at certain vascular entities. The authors have chosen just a sampling of the many practical uses of MRA in body imaging. With so many new developments, including new techniques and experimental contrast agents, its clinical applications are sure to become even more widespread.

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